

The mass discrepancy problem in O stars of solar metallicity. Does it still exist?

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Abstract. Using own and literature data for a large sample of O stars in the Milky Way, we investigate the correspondence between their spectroscopic and evolutionary masses, and try to put constraints on various parameters that might influence the estimates of these two quantities.

Keywords. stars: early type, stars: evolution, stars: fundamental parameters

1. Introduction

In its classical form, the so-called *mass discrepancy* refers to the systematic overestimate of evolutionary masses, M_{evol}^t , compared to spectroscopically derived masses, M_{spec} (e.g., Herrero et al. 1992). While continuous improvements in model atmospheres and model evolutionary calculations have reduced the size of the discrepancy (e.g., Repolust et al. 2004), however without eliminating it completely (Mokiem et al. 2007; Hohle et al. 2010; Massey et al. 2012), there are also studies (e.g., Weidner & Vink 2010) which argue that, at least for O stars in the Milky Way, the mass discrepancy problem has been solved.

2. Stellar sample and methodology

Our sample consists of 51 Galactic dwarfs, giants and supergiants, with spectral types ranging from O3 to O9.7. Forty one of these are cluster/association members; the rest are field stars. For 31 of the sample stars, we used own determinations of stellar parameters, obtained by means of the latest version of the FASTWIND code (Markova et al., in preparation); for the remaining 20, similar data have been derived by Bouret et al. (2012) and Martins et al. (2012a,b), employing the CMFGEN code instead.

For all sample stars, M_{spec} were calculated from the effective gravities corrected for centrifugal acceleration, whilst M_{evol}^t were determined by interpolation between available tracks along isochrones, as calculated by Ekström et al. (2012) (Fig1, upper panels) and Brott et al. (2011) (Fig.1, lower panels). To put constraints on biases originating from uncertain distances and reddening, in parallel to the classical $\log L/L_{\odot} - \log T_{\text{eff}}$ diagram (Fig. 1, left panels) we also consider a (modified) spectroscopic HRD (sHRD, Fig. 1, right panels)) that is independent of 'observed' stellar radii (for more information, see Markova et al. 2014 and Langer & Kudritzki 2014).

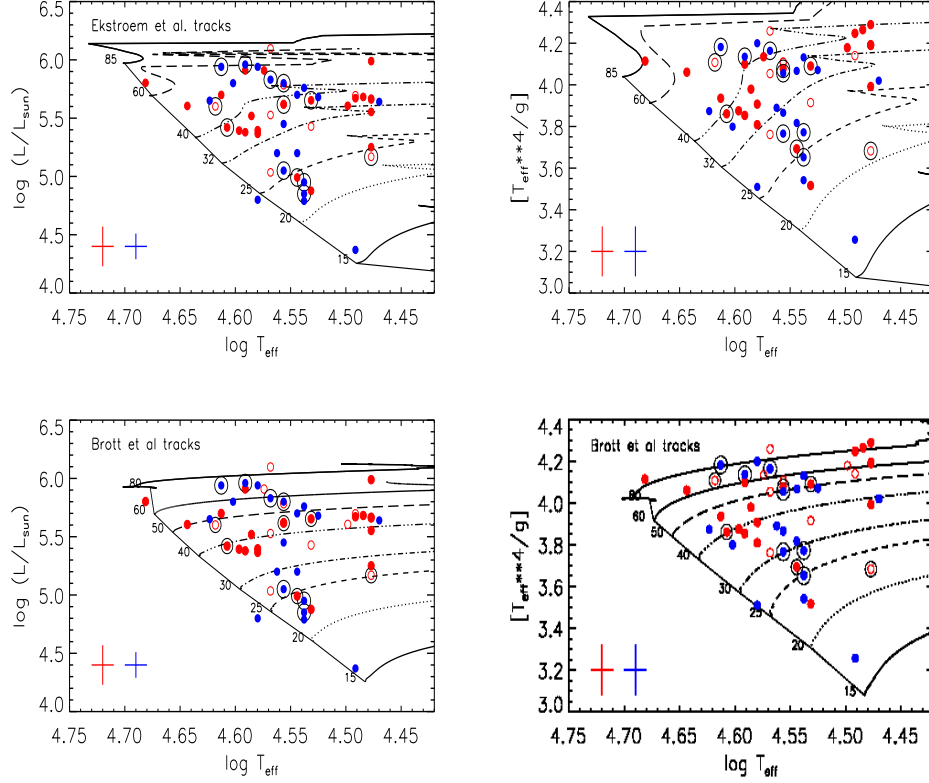


Figure 1. Classical (left) and spectroscopic (right) HR diagrams, resulting from Ekstroem et al. (upper panels) and Brott et al. (lower panels) tracks calculated with $v_{init} = 0.4 v_{crit}$ and $v_{init} = 300$ km/s, respectively, compared to own and complementary ‘observed’ data. Legend: red – FASTWIND data; blue – CMFGEN data; filled dots – cluster and association members; small open circles – field stars; large open circles – fast rotators ($v \sin i > 110$ km/s, see Markova et al. 2014)

3. Results

Our analysis indicates (see Fig.2) that

i) for objects with $M_{evol}^{init} > 35 M_{\odot}$, M_{evol}^t are either systematically lower (Ekstroem models) or roughly consistent (Brott models) with M_{spec} . As \dot{M} scales with $\log L/L_{\odot}$ (e.g., Vink et al. 2000; see also Puls et al., this Volume), and as – soon after the ZAMS – the Ekstroem models with rotation and $M_{evol}^{init} \geq 40 M_{\odot}$ become more luminous than the Brott models of the same M_{evol}^{init} and T_{eff} , we suggest that the *negative* mass discrepancy established for the Ekstroem tracks is most likely related to (unrealistically?) high mass-loss rates implemented in these models. (Warning! The good agreement between M_{spec} and M_{evol}^t read off the Brott tracks does not necessarily mean that the corresponding mass-loss rates are of the right order of magnitude, see next item)

ii) for objects with $M_{evol}^{init} < 35 M_{\odot}$, M_{evol}^t tend to be larger than M_{spec} . As massive hot stars can develop subsurface convection zones (Cantiello et al. 2009), and as they can be also subject to various instabilities, we are tempted to speculate that the neglect of turbulent pressure in FASTWIND and CMFGEN atmospheric models might explain the

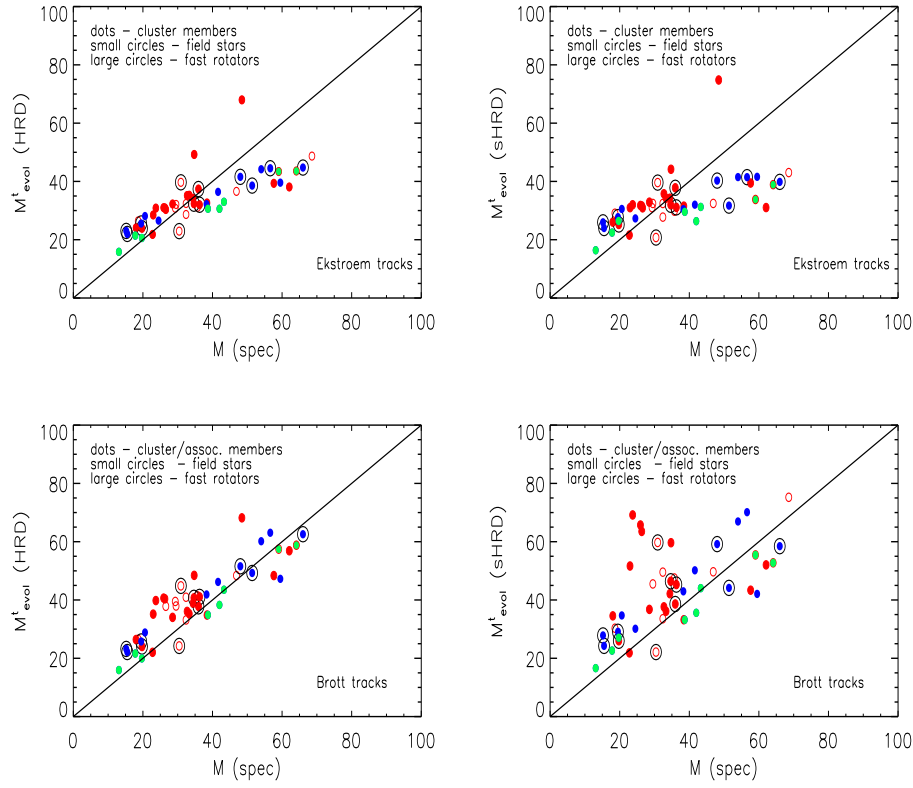


Figure 2. Comparison of M_{evol}^t and M_{spec} , for the cases of Ekstroem et al. (upper panels) and Brott et al. (lower panels) evolutionary models with rotation. Although for most of the sample stars the error bars (not indicated) cross the 1:1 line, there is a clear tendency for the less massive objects (M_{evol}^t below $35 \text{--} 40 M_{\odot}$) to show $M_{\text{evol}}^t > M_{\text{spec}}$. Regarding the more massive objects, the derived M_{evol}^t are either systematically lower (Ekstroem models) or roughly consistent (Brott models) with M_{spec} .

lower M_{spec} compared to M_{evol}^t †. Indeed, one might argue that if our explanation was correct a similar discrepancy should be present (but is not observed) for the more massive stars as well. However, such caveat might be easily solved if also the Brott models overestimate the mass-loss rates, as already suggested by Markova et al. (2014), and as also implied from up-to-date comparisons of theoretical and observed \dot{M} (e.g., Najarro et al. 2011; Cohen et al. 2014)

iii) while for most sample stars the correspondence between M_{spec} and M_{evol}^t does not significantly depend on the origin of the latter (HRD or sHRD), there are a number of outliers which, for the case of Brott tracks, demonstrate $M_{\text{evol}}^t(\text{sHRD}) > M_{\text{evol}}^t(\text{HRD})$, by a factor of 1.5 to 1.8. While specific reasons, such as, e.g., close binary evolution or homogeneous evolution caused by rapid rotation, can in principle explain discrepant masses read off the HRD and sHRD (Langer & Kudritzki 2014), it is presently unclear why this discrepancy does not appear in the Ekstroem tracks.

iv) the established mass discrepancy does not seem to be significantly biased by un-

† By including such a turbulent pressure, one would obtain a spectroscopic $\log g$ that is larger by 0.2 dex, for typical parameters and a turbulent speed of 15 km/s

certain stellar radii; the presence of surface magnetic fields, or systematically underestimated $\log g$ -values derived by means of the FASTWIND code (for more information, see Massey et al. 2013).

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References

- Bouret, J.-C., Hillier, D. J., Lanz, T., & Fullerton, A. W. 2012, *A&A* 544, A67
 Brott, I., de Mink, S. E., Cantiello, M., et al. 2011, *A&A* 530, A115
 Cantiello, M., Langer, N., Brott, I., et al. 2009, *A&A* 499, 279
 Cohen, D. H., Wollman, E. E., Leutenegger, M. A., et al. 2014, *MNRAS* 439, 908
 Ekström, S., Georgy, C., Eggenberger, P., et al. 2012, *A&A* 537, A146
 Herrero, A., Kudritzki, R. P., Vilchez, J. M., et al. 1992, *A&A* 261, 209
 Hohle, M. M., Neuhauser, R., & Schutz, B. F. 2010, *Astronomische Nachrichten* 331, 349
 Langer, N. & Kudritzki, R. P. 2014, *A&A* 564, A52
 Markova, N., Puls, J., Simón-Díaz, S., et al. 2014, *A&A* 562, A37
 Martins, F., Escolano, C., Wade, G. A., et al. 2012a, *A&A* 538, A29
 Martins, F., Mahy, L., Hillier, D. J., & Rauw, G. 2012b, *A&A* 538, A39
 Massey, P., Morrell, N. I., Neugent, K. F., et al. 2012, *ApJ* 748, 96
 Massey, P., Neugent, K. F., Hillier, D. J., & Puls, J. 2013, *ApJ* 768, 6
 Mokiem, M. R., de Koter, A., Evans, C. J., et al. 2007, *A&A* 465, 1003
 Najarro, F., Hanson, M. M., & Puls, J. 2011, *A&A* 535, A32
 Repolust, T., Puls, J., & Herrero, A. 2004, *A&A* 415, 349
 Vink, J. S., de Koter, A., & Lamers, H. J. G. L. M. 2000, *A&A* 362, 295
 Weidner, C. & Vink, J. S. 2010, *A&A* 524, A98